Rec'd PCT/PTO 03 MAR 2005

Three-Dimensional Grid Panel

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to a three-dimensional grid structure or panel. More particularly, the present invention relates to a grid structure or panel with enhanced stiffness and/or strength.

Related Art

The pursuit of structurally efficient structures in the civil, mechanical, aerospace and sports arenas is an ongoing quest. An efficient truss structure is one that has a high strength to weight ratio and/or a high stiffness to weight ratio. An efficient truss structure can also be described as one that is relatively inexpensive, easy to fabricate and assemble, and does not waste material.

Trusses are typically stationary, fully constrained structures designed to support loads. They consist of straight members connected at joints at the end of each member. The members are two-force members with forces directed along the member. Two-force members can only produce axial forces such as tension and compression forces in the member. Trusses are often used in the construction of bridges and buildings. Trusses are designed to carry loads which act in the plane of the truss. Therefore, trusses are often treated, and analyzed, as two-dimensional structures. The simplest two-dimensional truss consists of three members joined at their ends to form a triangle. By consecutively adding two members to the simple structure and a new joint, larger structures may be obtained.

The simplest three-dimensional truss consists of six members joined at their ends to form a tetrahedron. By consecutively adding three members to the tetrahedron and a new joint, larger structures may be obtained. This three dimensional structure is known as a space truss.

Frames, as opposed to trusses, are also typically stationary, fully constrained structures, but have at least one multi-force member with a force that is not directed along the member. Machines are structures containing moving parts and are designed to transmit and modify forces. Machines, like frames, contain at least one multi-force member. A multi-force member can produce not only tension and compression forces, but shear and bending as well.

Traditional structural designs have been limited to one or two-dimensional analysis resisting a single load type. For example, I-beams are optimized to resist bending and tubes are optimized to resist torsion. Limiting the design analysis to two dimensions simplifies the design process but neglects combined loading. Three-dimensional analysis is difficult because of the

difficulty in conceptualizing and calculating three-dimensional loads and structures. In reality, many structures must be able to resist multiple loadings. Computers are now being utilized to model more complex structures.

Complex three-dimensional structures or structural members have been developed with enhanced performance characteristics, such as increased strength, increased rigidity, reduced weight, etc. Such structures are described in U.S. Patent No. 5,921,048, issued July 13, 1999. Such structures can include two overlapping, off-set, tube-like structures. The first structure can include at least two, spaced-apart, helical components, and at least one reverse helical component attached to the at least two helical components. The helical and reverse helical components have a common longitudinal axis, but opposing angular orientations about the axis. In addition, each helical and reverse helical component can include at least three elongated, straight segments rigidly connected end-to-end in a helical configuration forming a single, complete rotation about the axis. Thus, the helical and reverse helical components form a first triangular-shaped cross section. In one aspect, the structure includes three helical components and three reverse helical components. In addition, the second structure can include rotated helical components and rotated reverse helical components, similar to, but rotated with respect to the helical and reverse helical components described above. Thus, the rotated helical and rotated reverse helical components form a second triangular-shaped cross section, rotated with respect to the first. In one aspect, the structure includes three rotated helical components and three rotated reverse helical components, for a total of twelve helical components. Together, the helical, reverse helical, rotated helical, and rotated reverse helical components appear as an imaginary tubular member-having a six-pointed star cross section when viewed along the axis. The various helical components intersect at external nodes and internal nodes. The components form six internal and six external nodes. Longitudinal or axial components may extend parallel to the axis and intersect the internal and/or external nodes.

Such three dimensional structures have shown great promise for various applications, such as trusses, poles, posts, etc. Such truss or pole configurations, however, can be difficult to use in other configurations due to the generally round configuration.

SUMMARY OF THE INVENTION

It has been recognized that it would be advantageous to develop a three-dimensional structure or panel with a flatter and thinner configuration, and with enhanced stiffness and strength.

The invention provides a three-dimensional grid panel with an intermediate grid disposed between and interconnecting two spaced-apart grids. The two spaced-apart grids each include: a) a first plurality of spaced-apart, elongated components; and 2) a second plurality of spaced-apart, elongated components, oriented transverse to the first plurality of components and intersecting the first plurality of components at nodes. The intermediate grid includes: 1) a first plurality of intermediate components, each extending between nodes of the two spaced-apart grids; and 2) a second plurality of intermediate components, oriented transverse to the first plurality of intermediate components and intersecting the first plurality of intermediate components at nodes, each of the second plurality of intermediate components extending between nodes of the two spaced-apart grids.

In accordance with a more detailed aspect of the invention, the components of the two spaced-apart grids and the intermediate grid can include continuous strands of fiber intersecting at the nodes. A plurality of continuous strands of fiber can be disposed in a repeating geometric pattern with the strands crossing and attaching to one another at nodes positioned at an outer perimeter of the grid panel. The strands can form discrete segments arranged sequentially with one another along the respective strands, and extending between the nodes

Additional features and advantages of the invention will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a is a perspective view of a grid panel in accordance with an embodiment of the present invention;

FIG. 1b is a partial perspective view of the grid panel in FIG. 1a;

FIG. 1c is a top view of the grid panel in FIG. 1a;

FIG. 1d is a front view of the grid panel in FIG. 1a;

FIG. 1e is a side view of the grid panel in FIG. 1a;

FIG. 1f is an exploded view of the grid panel of FIG. 1a;

FIG. 2a is a perspective view of another grid panel in accordance with an embodiment of the present invention;

FIG. 2b is an exploded view of the grid panel of FIG. 2a;

FIG. 3a is a perspective view of a grid panel in accordance with an embodiment of the present invention;

FIG. 3b is an exploded view of the grid panel of FIG. 3a;

FIG. 4a is a perspective view of a grid panel in accordance with an embodiment of the present invention;

FIG. 4b is an exploded view of the grid panel of FIG. 4a;

FIG. 5a is a perspective view of a grid panel in accordance with an embodiment of the present invention;

FIG. 5b is an exploded view of the grid panel of FIG. 5a;

FIG. 6a perspective view of a grid panel in accordance with an embodiment of the present invention;

FIG. 6b is a top view of the grid panel in FIG. 6a;

FIG. 6c is an exploded view of the grid panel of FIG. 6a;

FIG. 6d is a partial perspective view of the grid panel in FIG. 6a showing the lower or left grid and the intermediate grid;

FIG. 7a is a perspective view of another grid panel in accordance with the present invention;

FIG. 7b is an exploded view of the grid panel of FIG. 7a;

FIG. 8 is a schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

FIG. 8b is a partial schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

FIG. 8c is a partial schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

FIG. 9 is a perspective view of another grid panel in accordance with an embodiment of the present invention; and

FIG. 10 is a perspective view of another grid panel in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Alterations and further modifications of the inventive features illustrated herein, and additional applications of the principles of the inventions as illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the invention.

Some aspects of three-dimensional structures are described in U.S. Patent 5,921,048, issued July 13, 1999, which is herein incorporated by reference. As illustrated in FIGs. 1a-f, a three-dimensional grid structure or panel, indicated generally at 10, in accordance with the present invention is shown. As described above, other truss or pole structures have been developed that have generally tubular or pole-like shapes. The grid panel 10 of the present invention has a flatter configuration suitable for use in situations that can require a panel structure. The flat configuration is relatively broad in two dimensions (such as longitudinally and laterally), and relatively thin in a third dimension (such as thickness). In one aspect, the grid panel 10 can be disposed in a planar layer, as shown. In another aspect, the grid panel 10 can be disposed in an open curvilinear or arcuate layer.

The structure and geometry of the grid panel 10 may be described in numerous ways. The grid panel 10 can include a plurality of elements or members 12 arranged in a repeating pattern along the grid panel 10. The elements or members 12 can be relatively straight, and can be combined together to form the repeating patterns in the panel. The grid panel 10 may be conceptualized and described as a plurality of elongated components 20 extending along and through the grid panel. The components 20 can be elongated, and can extend across the panel 10. The components 20 can be straight, or can alternate back and forth, as described below. The components can be formed or conceptualized as a plurality of sequential members 12 coupled end-to-end. The components 20 can have various different angular orientations with respect to one another. In addition, the components 20 can be provided in groups or arrays of components with similar orientations, with the components 20 of each group being spaced-part from one another in an array. Furthermore, groups of components 20 can be combined into grids or sub-grids of the grid panel, with the grids including groups of components with different orientations so that the components 20 from one group intersect and/or transverse the components 20 of another group. Each component 20 also can include a plurality of sequential discrete or straight segments 22 connected end-to-end in straight and/or angled configurations. As described in greater detail below, each component 20 can be formed by a tow or strand of continuous fibers that extend through and along the grid panel, and intersect or connect with other tows or strands at nodes, to form a grid panel that has enhanced rigidity and strength, and reduced weight.

The grid panel 10 can include two spaced-apart grids, such as first and second, left and right, or lower and upper grids 24 and 26, that are sub-grids or sub-structures of the grid panel 10. The two grids 24 and 26 are spaced-apart from one another, and can be oriented substantially parallel with one another. In addition, the two grids 24 and 26 are formed by components 20, and can have a thickness defined by, or substantially equal to, a thickness of the

components 20 that form the individual grids 24 and 26, or the strands of fiber that form the components. An intermediate grid 28 is disposed between, and extends between the two spaced-apart grids 24 and 26, and joins or attaches the two grids 24 and 26 together. The intermediate grid 28 also is formed in part by components 20, but has a thickness defined by the spacing or distance between the spaced-apart grids 24 and 26. The grid panel 10 has a thickness that is substantially less than a width and a height of the grid panel 10, or a width and a length of the grid panel. The thickness is measured across the two grids 24 and 26, while the width and height (or length) are measured along the two grids.

Referring to FIG. 1f, a first or lower grid 24 can include a plurality of elongated and spaced-apart longitudinal components 30, and a plurality of elongated and spaced apart lateral components 34. The longitudinal components 30 have a similar orientation, are disposed in a common layer, and are arrayed in a spaced-apart relationship. Similarly, the lateral components 34 have a similar orientation, are disposed in a common layer, and are arrayed in a spaced-apart relationship. The longitudinal components 30 and lateral components 34 have transverse orientations with respect to one another, such that the longitudinal and lateral components 30 and 34 can cross or intersect one another at nodes or primary nodes 36. The components 30 and 34 of the first grid 24 can be disposed in a planar layer and can be oriented orthogonal to one another, as shown. Thus, the components 30 and 34 can outline square or rectangular shapes. The elongated components 30 and 34 can be substantially straight, as shown.

The second or upper grid 26 can be similar in many respects to the first or lower grid 24 with a plurality of longitudinal components 40 intersecting or crossing a plurality of lateral components 42 at nodes 36, and oriented transverse to the lateral components 42. The first and second grids 24 and 26 can be off-set with respect to one another, or so that the nodes 36 of each grid are off-set with respect to one another. Thus, the nodes 36 of the first grid 24 are positioned across from the square or rectangular spaces of the second grid 26, while the nodes 36 of the second grid 26 are similarly positioned across from the square or rectangular spaces of the first grid 24. The nodes 36 can be disposed about a perimeter or exterior of the grid panel 10.

The intermediate grid 28 can include a plurality of elongated, spaced-apart intermediate components, including a first plurality of first intermediate components 46, and a second plurality of second intermediate components 48. The first intermediate components 46 have a similar orientation, and are arrayed in a spaced-apart relationship. Similarly, the second intermediate components 48 have a similar orientation, and are arrayed in a spaced-apart relationship. The first and second intermediate components 46 and 48 have transverse orientations with respect to one another such that the intermediate components 46 and 48 can

cross or intersect one another at the nodes 36. The intermediate components 46 and 48 of the intermediate grid 28 can be oriented orthogonal to one another, as shown. In addition, the intermediate components 46 and 48 can extend back and forth between the first and second grids 24 and 26. The intermediate components 46 can include sequential segments 22 that alternate back and forth between the two grids 24 and 26, and thus alternate orientations. Thus, the various components 30, 34, 46 and 48 (or 40, 42, 46 and 48), or members 12 thereof, can outline pyramid-shaped spaces with five sides, including four triangular sides and one square or rectangular side.

As described above, the first and second grids 24 and 26, or nodes 36 thereof, can be off-set with respect to one another. Thus, the intermediate components 46 and 48 extend from nodes in one grid on a diagonal to the nodes in the other grid. The intermediate components 46 and 48 can extend diagonally or transverse to both the grids 24 and 26, and to the longitudinal and lateral components 30 and 34 (and 40 and 42). While the longitudinal and lateral components 30 and 34 can extend longitudinally and laterally along the grid panel 10, the intermediate components 46 and 48 can extend both diagonally across the grid panel 10, and back and forth through the thickness of the grid panel 10.

The grid panel 10 defines a layer that contains the grid panel. Similarly, the first and second grids 24 and 26, and the intermediate grid 28, also define layers within the layer of the grid panel 10. The first and second grids 24 and 26 define first and second layers. The first layer is defined by and contains the plurality of lateral and longitudinal components 30 and 34. Similarly, the second layer is defined by and contains the plurality of lateral and longitudinal components 40 and 42. The first and second layers can have a thickness equal to a diameter of the components 30, 34, 40 and 42, or strands of fiber. An intermediate layer is defined by and contains the diagonal components 46 and 48. The first and second layers can be relatively thin with respect to the intermediate layer, while the intermediate layer can be relatively thick with respect to the first and second layers. In addition, the layers can be planer or flat, as shown. Alternatively, the layers can be curved.

Referring to FIGs. 2a-b, another grid panel 10b is shown that is similar in many aspects to the grid panel described above. The first and second spaced-apart grids 24b and 26b additionally include a plurality of diagonal components, including a first plurality of first diagonal components 50 and 54 (for respective first and second grids 24a and 24b), and a second plurality of second diagonal components 52 and 56 (for respective first and second grids 24a and 24b). The first and second diagonal components 50 and 52, and 54 and 56, are oriented transverse both to each other, and to the longitudinal and lateral components 30 and 32, and 40

and 42. The first and second diagonal components 50 and 52, and 54 and 56, intersect each other at secondary nodes 58, and intersect the longitudinal and lateral components 30 and 32, and 40 and 42, at primary nodes 36.

Referring to FIGs. 3a-b, another grid panel 10c is shown that is similar in many respects to those described above. Each of the first and second spaced-apart grids 24c and 26c includes three different groups of similar components, with the components of each group having a different angular orientation with respect to one another, such as at sixty degree angles with respect to one another. The first grid 24c can include a first group of first components 60, a second group of second components 62, and a third groups of third components 64. As described above, the components of each group can have a common orientation and a common plane, and can be arrayed or spaced-apart from one another. The first, second and third components 60, 62 and 64 can transverse each other, and intersect each other at nodes 36. Thus, the components form triangle-shaped spaces therebetween. The second grid 26c similarly can include first, second and third groups of first, second and third components 66, 68 and 70. The spaced-apart grids 24c and 26c can be positioned or oriented with respect with one another to match, as opposed to being off-set, so that the nodes 36 of each grid align with the nodes of the other grid.

The intermediate grid 28c also includes three different groups of similar components, namely a first group of first components 72, a second group of second components 74, and a third groups of third components 76. The components of each group can have similar orientations, and can be arrayed in a spaced-apart relationship. The first, second and third intermediate components 72, 74 and 76 have transverse orientations with respect to one another such that the intermediate components can cross or intersect one another at the nodes 36. As described above, the intermediate components can extend back and forth between the first and second grids 24c and 26c. Thus, the various components can outline pyramid-shaped spaces with seven sides, including six triangular sides and one hexagon-shaped side.

Referring to FIGs. 4a-b, another grid panel 10d is shown that is similar in many respects to those described above. Unlike the grid panel 10c shown in FIGs. 3a-b, however, the grid panel 10d in FIGs. 4ab include first and second spaced-apart grids 24c and 26c that are off-set with respect to one another, or whose nodes are off-set with respect to one another. In addition, the off-set of the spaced-apart grids 24c and 26c changes the configuration of the intermediate grid 28d. The intermediate grid 28d includes different groups of intermediate members 78 configured to form pyramid-shaped spaces with four triangular sides.

Referring to FIGs. 5a-b, another grid panel 10e is shown that is similar in many respects

to those described above. The second or upper grid 26e includes different groups of diagonal members 80, where the diagonal members in each group are spaced-apart, but with different intervals or at different distances. For example, the spaces between the diagonal members 80 can include larger and smaller alternating spaces.

Referring to FIGs. 6a-d, another grid panel 10f is shown that is similar in many respects to those described above. First or lower grid 24f includes lateral and longitudinal components 30 and 34, where the lateral components 34 are spaced-apart, but with different intervals or at different distances. For example, the spaces between the lateral 34 can include larger and smaller alternating spaces. The first grid 24f can include diagonal components, as shown in FIG. 6c. The intermediate grid 28f can include intermediate components 90 that both 1) traverse the space between the first and second grids, as described above, and 2) extend along the first and second grids, indicated at 92 in FIG. 6d.

Referring to FIGs. 7a-b, another grid panel 10g is shown that is similar in many respects to those described above. The first or lower grid 24g can include diagonal components 96 that are non-linear, or that are not straight. The diagonal components 96 can include sequential segments with alternating and different angular orientations with respect to one another.

In one aspect, the first and second grids can have similar configurations, as shown in FIGs. 1a-4b. In another aspect, the first and second grids can have different configurations, as shown in FIGs. 5a-7b.

The various components can define an interior space in the grid panel that is substantially void except for the intersecting components of the intermediate grid. Alternatively, the interior space can be filed with another material, such as foam, to add additional structural or functional aspects to the panel, such as thermal or noise insulation. In addition, the grids themselves can define an interior space between the components that is substantially void. Alternatively, these interior spaces can also be filled with another material. In addition, a skin or panel can be disposed on one or both of the first and second grids. The nodes can be positioned at a perimeter of the grid panel. The nodes can be regularly and evenly spaced, or can be irregularly spaced.

Although the above grid panels have been described with respect to various different configurations, it will be appreciated that other configurations are possible and are within the scope of the invention.

As stated above, the grid panel can be formed of composite material, such as fiber in a resin matrix. The fibers preferably are continuous, and can be carbon, glass, basalt, aramid, Kevlar, polyethylene, nylon, bamboo, or other natural or man-made fibers. The resin can be any

type, such as a thermoplastic resin, like PCV, or thermoset resin, like epoxy or vinyl ester. The repeating geometric shapes of the grid panel can be formed from a plurality of continuous strands or tows of fiber extending along the grids. Each component of the grid panel can include a plurality of continuous fibers. The strands of fiber can cross and attach to one another at the nodes. The strands, tows or fibers of the various components can be twisted, wrapped, and/or braided together to reduce gaps, particularly at intersections or nodes. The various components can be formed of a group of outer fibers wrapped or braided around a core of inner fibers. For example, a braided sleeve can encapsulate a core of straight or twisted fibers.

The fibers of the various components can be interwoven or overlap at the intersections or nodes. For example, the fibers of the longitudinal components can pass between the fibers of the lateral components. It is of course understood that the fibers of all the components can pass between or intersect the fibers of other components. For example, the fibers of the one component can be maintained in a single tow or strand with the fibers of another component surrounding the one component. In addition, it is understood that the components can merely pass by one another, without interweaving, overlapping or intersecting. The overlaying or intersecting fibers, however, can form gaps between the fibers. As previously mentioned, such gaps can reduce the strength of the structure by as much as 90%. It will be appreciated that the strength of the grid panel is derived from the synergy of the collective fibers as a bundle. Thus, isolating or separating fibers can have a detrimental effect on the strength of the structure. Therefore, as described above, the fibers, strands or tows can be twisted, wrapped, braided, or wrapped with a braid to condense the fibers and reduce any gaps, and increase the strength of the fibers, and the grid panel.

In addition, the various components can intersect at a single node at a single location or position, as described above. It will be appreciated that the intersection of many fibers can create a bulky node, and may introduce gaps. In addition, the intersection of the many fibers can create nonlinearities in the fibers that also degrade their structural performance. In one aspect, the nodes or intersections can be off-set with respect to one another. Thus, the nodes or intersections can be off-set, or spaced apart, forming a grouping of different nodes or intersections in close proximity to one another. Thus, a single node or point of intersection can be separated into two or more nodes or intersections to reduce the bulk of the intersections and to reduce gaps.

In one aspect, the grid panel can be configured with a taper along one or more directions. In another aspect, the grid panel can be configured with an arcuate shape, and can thus be curved. The nodes on one side can be located closer together than those on another side.

Similarly, the segments on one side can be longer than those on another side. It will be appreciated that the grid panel can be non-symmetrical.

In another aspect, the grid panel can have tapering components. For example, the longitudinal components can taper. The tapering components can be formed by strands or tows of fiber that are thicker and stronger at one end or portion of the structure, and thinner and lighter at another end or portion. The number of fibers in the strands or tows can be increased or reduced to form the taper.

The panels of the present invention can be fabricated or cast in free-space from a method referred to as tensioned fiber placement or casting. The method involves interlacing one or more rotating or alternating strands of transverse fibers with an array of tensioned, longitudinal fibers to form a support skeleton suitable for further interlacing or over-wrapping of other fiber strands at varying orientations. These collective, interwoven, fibers are coated with resin and cured in this tensioned, skeletal configuration to form a sturdy structure with very high load capacity and stiffness, but very low weight.

A plurality of continuous fibers can be pulled from a feed source along a processing path about a longitudinal axis. At least some of the fibers can be wound around the longitudinal axis in opposite directions to form the various components that intersect at nodes. The fibers can be engaged along the processing path substantially only at locations localized at select nodes without substantially engaging the components. The select nodes can be maintained radially outwardly from the longitudinal axis to create sequential discrete segments in the intermediate components. The select nodes can be engaged from outside the components or panel. Thus, the structure can be formed without a traditional internal mandrel.

Referring to FIGs. 8a-c, an apparatus 100 and method are shown for fabricating such a grid panel from continuous fibers or tows 150 or strands of fibers. The apparatus 100 can be configured to fabricate the various grid panels having various different configurations.

The apparatus 100 can include a frame or base support member with a processing path 158 along which the continuous fibers 150 are arranged into the grid panel 10. The processing path 158 can have a longitudinal axis that is concentric with the grid panel. The continuous fibers 150, and resulting grid panel 10, are drawn or pulled through the processing path 158 of the apparatus 100, as indicated by arrow 160. A puller can pull the continuous fibers 150 and/or grid panel 10 through the processing path 158 and maintain the fibers 150 in a taut condition. The fibers 150 are disposed in the processing path 158, and pulled taut, to provide an axial support configuration which forms an operating skeleton for assembly of the grid panel 10. This skeletal structure enables formation of complex open structures without dependence upon a

traditional internal mandrel, die, or other internal shaping device configured to support the entire surface of an object. A plurality of fiber feed sources 162 can be associated with or coupled to the frame or base support member to provide the continuous fibers 150. Thus, the continuous fibers 150 can be drawn from the fiber feed sources 162 and through the apparatus 100 or processing path 158. The fiber feed sources 162 can include center feed coils or outer feed spools about which the continuous fibers 150 are wound. Any fiber source that facilitates continuous release of a tensioned fiber can be utilized in this apparatus.

The apparatus 100 can include a separate fiber feed source 162 for each component. It is of course understood that the number of fiber feed sources 162 depends on the number of components, which can vary depending on the configuration and size of the grid panel to be fabricated.

In addition, each fiber feed source 162 can provide a plurality of fibers or tows 150 that are grouped together in the strands to form the individual components of the grid panels 10. For example, a single tow can be formed of several thousand individual fibers. The plurality of fibers or tows 150 from each fiber feed source 162 can be twisted or rotated together, wrapped, braided, or overwrapped with a braid to form the strands.

A rotational or displacement element(s) can be associated with the fiber feed sources 162 and frame or base support member 154 to displace the fibers 150 or fiber feed sources 162 around the processing path 158. The displacement element(s) can wind the continuous fibers 150 in opposite directions to form the transverse diagonal components. The displacement element(s) can include tracks on the paths along which the fiber feed sources 162 travel. The displacement element(s) can include displacement frames to which the fiber feed sources 162 are coupled so that the fiber feed sources also travel along the paths as the displacement frames displace.

For example, the plurality of fiber feed sources can include stationary fiber feed sources from which longitudinal components are pulled straight through the processing path. Other fiber feed sources can extend back and forth with respect to the processing path to form the lateral components. Other fiber feed sources can travel back and forth along the path 164 to form the intermediate components. Because the intermediate components transverse one another, the path 164 can include passing locations 166 where the fiber feed sources can pass one onother.

An orientation guide member 168 can be associated with the frame or base support member, and positioned between the fiber feed sources 162 and the processing path 158, to receive the continuous fibers 150 from the plurality of fiber feed sources 162 for angularly reorienting the continuous fibers 150 to a desired pre-processing configuration. The orientation

guide member 168 can be a ring for guiding the fibers 150 from the fiber feed sources 162 to the processing path 158. The preprocessing configuration represents the reorientation of the fibers 150 from the feed sources 162 to a longitudinally stressed skeletal structure along the processing path 158.

An intermediate support element or member 180 can be disposed at the processing path 158 and associated with the frame or base support member. The intermediate support element 180 can include a plurality of engagement members 184 disposed around the processing path 158 to engage the nodes 36 of the components, and to direct and maintain the nodes of the components outwardly. Thus, the intermediate support element 180 and/or engagement members 184 form the sequential discrete or straight segments 22 in the components. The intermediate support element 180 and/or engagement members 184 support the fibers 150 in the configuration of the grid panel 10. As discussed in greater detail below, the engagement members 184 can travel with the grid panel 10 as the fibers 150 are drawn through the processing path 158. The engagement members 184 and/or intermediate support element 180 also can be a puller or traction member to pull the fibers through the processing path. The intermediate support element 180 can be disposed around the grid panel 10 with the engagement members 184 engaging the nodes36 from the exterior of the grid panel 10, as shown. The engagement members 184 can include hooks, notches, or grooved heads around which the fibers 150 are wound. The engagement members 184 and/or intermediate support element 180 form an external support structure for the fibers, as opposed to a traditional internal mandrel configured to support the entire inner surface of the grid panel.

The engagement members 184 can engage or contact the grid panel substantially only at the nodes. The engagement or contact can be localized at or along the nodes. The engagement members 184 can bias the nodes outwardly. Thus, the engagement members 184 can exert an outward force on the grid panel at the nodes. The engagement members 184 form the straight segments in the grid panel. The engagement members 184 can establish free space points intermittently which operate to support the nodes of the grid panel without a traditional internal mandrel that is continuous.

The intermediate support element 180 and/or engagement members 184 can be outwardly displacable and operable with respect to the fibers 150 to intermitently draw or displace fibers 150 outwardly and along a path to a stable, extended position representing the grid panel. Thus, the configuration of the grid panel or operating skeleton can be maintained without the aid of an internal mandrel or cavity die.

The intermediate support element 180 and/or engagement members 184 can be located outwardly to correspond to the desired size and shape of the grid panel. In one aspect, the engagement members 184 are adjustably positioned so that a grid panel of any desired size or shape can be formed. The intermediate support element 180 and/or the engagement members 184 can be displaced outwardly during processing so that changes in size or thickness can be accomplished during processing.

The engagement members 184 can be provided in sets or groups corresponding to the number of nodes. In another aspect, numerous sets can be provided, with only some being used depending on the number of desired nodes.

The adjustable nature of the engagement members 184 and/or support element 180 can provide for easier manufacture of structural components typically made of geometry specific tooling. It will be appreciated that minor changes made to traditional structures requires that a new mandrel be machined.

As described above, the intermediate support element 180 and/or engagement members 184 can support and maintain the fibers from outside the structure. Thus, the intermediate support element 180 and/or engagement members 184 do not interfere with the various segments that cross or intersect the interior of the grid panel. As discussed above, a traditional, internal, continuous mandrel can be difficult to withdraw from the interior of the grid panel because of the segments that cross or intersect the interior.

A resin applicator can be associated with the frame or base support member to apply resin to the continuous fibers 150, as is known in the art. The resin applicator can include a nozzle to spray or drip resin onto the fibers. The resin can be applied to the fibers 150 while the fibers 150 are supported by the engagement members 184. In addition, the resin can be applied to the fibers 150 prior to engagement by the engagement members 184 so that the engagement members do not block the application of the resin. A nozzle or spraying is one example of means for applying resin to the fibers. Other means for applying resin to the fibers include, for example, a resin bath through which the fibers are drawn, multiple spray nozzles, prepreg (pre-impregnated) fibers, etc. Applying the resin to the fibers creates a liquid resin/fiber composite.

An oven, heat source, or other curing device can be associated with the frame or base support member to help cure the resin, as is known in the art. The resin can be cured while the fibers 150 are supported by the engagement members 184. An oven or heat source is one example of means for curing the resin or the liquid fiber/resin composite. Other means for curing the resin include, for example, heat, forced air, UV radiation, microwaves, electron beam,

laser beam, etc. Curing the resin or liquid resin/fiber composite creates a sturdy, rigid, three-dimensional truss structure capable of bearing multidirectional loading.

A puller or traction member can be associated with the frame or the base support member to apply axial tension and pull the continuous fibers 150 and/or the grid panel through the processing path 158. The puller also can engage the cured resin/fiber composite structure, such as with the use of a gear-like device with teeth that intermesh with the cured structure. The puller also can engage the structure with graspers that grasp the structure or components, such as the axial components. The graspers can be pneumatically, hydraulically, electrically or mechanically actuated. As stated above, as the grid panel and fibers are pulled through the processing path, the engagement members 184 and/or intermediate support element 180 can move with the grid panel. In one aspect, the engagement members 184 can move along the intermediate support element 180. In another aspect, the engagement members 184 also can be used as the puller or traction member. Thus, the grid panel 10 can be fabricated with any desired length, while at the same time having variable thickness.

A cutter also can be associated with the frame or base support member to cut the grid panel 10 to a desired length. The cutter can include a blade to cut through the various components and/or segments. In addition, the cutter can include a high-pressure fluid jet, water jet, laser beam, or any other cutting mechanism.

Further explanation and example of such a method and apparatus for fabricating complex, composite structures can be found in International Application No. PCT/US02/26178, published February 27, 2003 (International Publication No. WO 03/016036), which is herein incorporated by reference.

Alternatively, the panels described above can be made by other methods and tools, such as internal mandrels. The mandrel can be configured with heads or other fiber holder to hold the fibers at the locations of the nodes. The fibers can be wrapped around a mandrel to form the desired configuration of the panel. The mandrel can be dissolved or collapsed to remove the mandrel from the fibers, after the resin has cured. Examples of other methods for fabricating such structures can be found in U.S. Patent Application No. 10/343,133, and International Application No. PCT/US01/23636 published February 7, 2002 (International Publication No. WO 02/10535), which are herein incorporated by reference.

Referring to FIG. 9, another grid panel 10h is shown that is similar in many respects to those described above. The grid panel 10h has an arcuate or curved shape, so that the grid panel and components are disposed in an acruate or curved layer. The grid panel 10h can have an axis 190. Unlike the grid panel described above, however, the grid panel 10h in FIG. 9 includes first

and second spaced-apart grids 24h and 26h that are curved. The curvature of the grids 24h and 26h can be concentric, as shown. The grids 24h and 26h can include respective longitudinal components 30h and 40h that can be parallel with the axis 190. In addition, the grids 24h and 26h can include respective lateral components 34h and 42h that curve about the axis 190. The longitudinal and lateral components 30h and 34h of the first grid 24h can intersect one another at outer nodes 192, while the longitudinal and lateral components 40h and 42h of the second grid 26h can intersect at inner nodes 194. The outer nodes 192 can be spaced-apart a distance d1 greater than a distance d2 of the inner nodes 194. Thus, the nodes on one side can be located closer together than the nodes on the opposite side. An intermediate grid 28h can extend between the nodes 192 and 194 of the grids 24h and 26h.

Referring to FIG. 10, another grid panel 10i is shown that has a wavy profile or cross-section. Thus, the first and second grids 24i and 26i, and the intermediate grid 28i, can have multiple curvatures.

In addition, a panel can have a bowl, partially spherical or spherical shape, or with curves in two dimensions.

It is to be understood that the above-referenced arrangements are only illustrative of the application for the principles of the present invention. Numerous modifications and alternative arrangements can be devised without departing from the scope of the present invention while the present invention has been shown in the drawings and fully described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments(s) of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications can be made without departing from the principles and concepts of the invention.